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A Large-Scale Wetland Conversion Project in Southeastern Missouri: Sustainability of Water and Soil

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Abstract

Wetland conversion in southeastern Missouri initiated with the Little River Drainage Project (1914–1924) resulting in the permanent drainage and conversion of 5 million acres (2 million hectares) to productive agricultural land. Given that this ancestral wetland conversion has totally replaced the wetland ecosystem with prime agricultural land and with this conversion, the loss of wildlife habitat is nearly complete, the question remains what actions are now possible to restore key wetland soil pathways to support soil health and water quality. Key to any corrective practices involves agricultural producer involvement and commitment. The emerging concept of soil health supports the use of cover crops that promote soil structure development and soil carbon sequestration, each perceived as supporting farm profitability. Government programs supporting field flooding during the off-season supports migratory water fowl. Farming practices such as furrow irrigation and allied technologies for rice production limit aquifer overdraft. Edge of field technology involving riparian strips and denitrification bioreactors support downstream water quality by limiting nitrate and phosphate off-field migration. The result is that emerging technologies (i) support farm profitability and environmental stewardship and (ii) which are designed specifically to provide farming practice compatibility with the soil and water resources re-establishes some wetland mechanisms appropriate for long-term land and water resource sustainability.

Keywords: wetland conversion, hydric soils, soil health, edge-of-field technologies, cover crops

1. Introduction

In the USA, it is estimated at 90% of the wetlands that existed prior to European discovery and settlement have been converted to other uses, most notably agricultural usage [1]. Land drainage has been extensive in many states, such as Alaska, Florida, Indiana, Minnesota, Missouri, and Wisconsin. Land drainage, both subsurface tile-drainage and surface drainage with and without diversionary earthworks, dramatically altered these ecosystems and their attendant soil and plant processes. Large scale and substantial changes in vegetation, water availability, nutrient flow, and other characteristics of these ecosystems impact the flora, negatively impact water quality, and reduce soil health, yet the economic impacts are important social restraints on returning these areas and regions to their pre-European settlement status.

Given that the return of thousands of hectares of cropland back to wetland status is not a pragmatic solution, current features of USA agriculture policy attempt to support best use methods that both support farm profitability and align sustainable agriculture production to encourage soil health, organismal diversity, and environmental stewardship.

2. Wetlands and prior converted wetlands

Our purpose in creating this manuscript is to chronical re-establishment of important wetland plant-soil interactive processes in converted wetlands to support soil health, water quality, environmental stewardship and biological diversity, while maintaining agricultural productivity. Although programs exist to re-create wetlands from agriculture land, there are pragmatic social, political and economic realities that limit their large-scale application. The application of emerging technologies and governmental policies, designed to support important soil attributes reflective of the original wetland status, provide opportunities for both environmental advancement, and agricultural profitability.

To be designated as “Prior Converted Cropland” in the USA, all the following land criteria must be validated: (i) cropped prior to December 23, 1985 with an agricultural commodity, (ii) cleared, drained or otherwise manipulated to make it possible to plant a crop, (iii) continued to be used for agricultural purposes, and (iv) does not flood or pond for more than 14 days during the growing season [1]. Vital wetland soil processes that need to be re-emphasized in converted wetlands include: (i) synthesis and subsequent maintenance of soil organic carbon, (ii) maintenance of soil biological diversity, including microbial populations, (iii) erosion abatement, (iv) unimpeded activity of nutrient cycles, especially the nitrogen cycle, (v) development of the original soil structure fabric, (vi) appropriate water transport within and among pedons, and (vii) encouragement of microbial-driven ecosystem processes that reduce excessive plant nutrients and degrade applied agrichemicals within suitable time frames.

3. The study area and the Little River Drainage System in Missouri

The study area ranges from the St. Francois River in the west to the Mississippi River in the east and ranges from the headwater diversion channel at Cape Girardeau Missouri to the

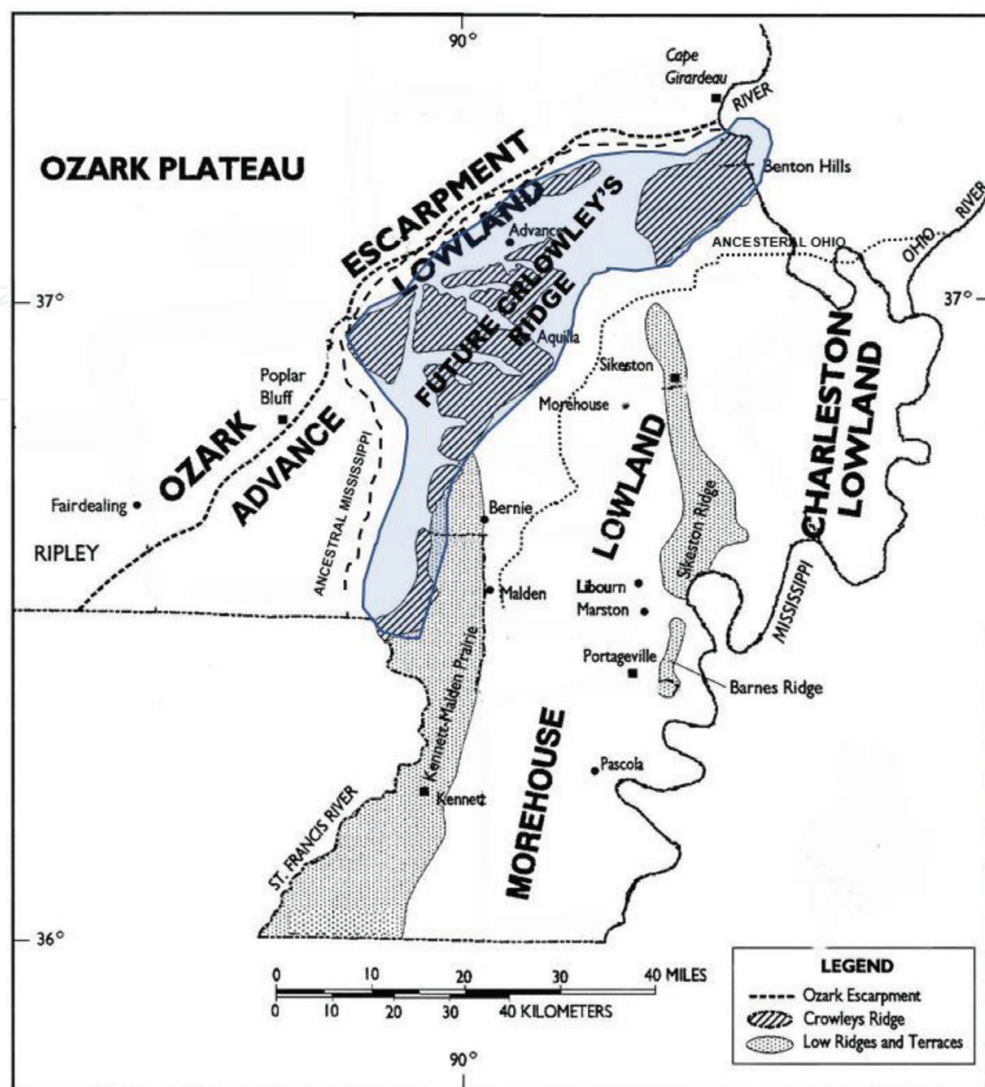


Figure 1. Landscape features of Southeastern Missouri.

Missouri – Arkansas border (**Figure 1**). Approximately 5 million acres (2 million hectares) of landscape was drained from its status as wetlands to produce an intensive agricultural setting. The entire drainage system is maintained by taxes levied on agricultural producers [2].

A series of north to south drainage ditches (1541 km) and levees (490 km) were constructed to transport water from southeast Missouri into Arkansas and then into the Mississippi River. The Headwater Diversion Channel was constructed to intercept drainage of the Castor and Whitewater Rivers, transporting this water eastward into the Mississippi River. Dams created the Clearwater and Wappapello Reservoirs by intercepting drainages of the St. Francois and Black Rivers, respectively [2].

4. Climate of Southeastern Missouri

The climate is continental humid. The average daily January temperatures are 2 and 4°C (35 and 39°F) at Cape Girardeau and Kennett, Missouri, whereas the average summer

temperatures are 25 and 26°C (77 and 79°F) at these locations. As expected, June–August are the warmest months. The growing season generally has 210-plus frost-free days. The soils are frozen only at the surface and only for brief periods of time. The rainfall is reasonably well distributed, with the total annual precipitation averaging 1.14 m at Cape Girardeau and 1.27 m at Kennett. The remnants of tropical storms from the Gulf of Mexico may provide more than 0.25 m of rainfall during a rainfall event [3].

5. Wetlands and hydric soils in the study area

We define wetlands as soilscape transitional between terrestrial and aquatic systems that support hydrophytes and possess an undrained substratum having anoxic conditions, typically having a water table for some portion of the time when the soil temperature is above biologic zero. In our study area, a large-scale drainage management system has been implemented to produce agriculture lands; however, the ancestral wetlands would have been classified as southern deepwater swamps and riparian forested wetlands [4]. Hydric soils are defined as “soil that is saturated, flooded or ponded long enough during the growing season to develop anaerobic conditions in the upper part” [5]. Prolonged anaerobic conditions promote selected biogeochemical soil processes that modify the soil morphology, such as (i) organic matter accumulation, (ii) iron and manganese oxyhydroxide transformations/depletions/accumulations, (iii) sulfate-sulfide transitions, nitrogen transformations, and (iv) biogeochemical nutrient cycle alterations. These indicators are used to delineate hydric soils; however, in the USA the indicator criteria may vary among the major land resource areas. Wetland delineation in the USA is based on the presence of hydric soils, the local hydrology, and wetland indicator plants.

6. Landforms and vegetation

Much of the natural vegetation has been removed and replaced with agricultural enterprises. Depressional areas consisting of backswamp deposits typically supported bald cypress (*Taxodium distichum* L.), water tupelo (*Nyssa sylvatica*), sweetgum (*Liquidambar styraciflua* L.), and multiple species of canes, rushes, and grasses, whereas recent meander belt deposits have willows (*Salicaceae* sp.), eastern cottonwoods (*Populus deltoides* Marsh.), American elm (*Ulmus americana* L.), yellow poplar (*Liriodendron tulipifera* L.), and boxelder (*Acer negundo* L.). Mixed forest species existed on well-drained to moderately well drained soils residing on variably textured alluvium and natural levees. Mixed forest species included: southern red oak (*Quercus falcata* L.), willow oak (*Quercus phellos*), white oak (*Quercus alba* L.), swamp white oak (*Quercus bicolor* Willd.), and shagbark hickory (*Carya ovata* Mill.).

The Southeast Lowlands Groundwater Province (SLGP) is bounded on the north and west by the Ozark Plateau, with the transition from the SLGP to the Ozark Plateau called the Ozark escarpment. The eastern boundary is the modern Mississippi River and the southern boundary is the Missouri-Arkansas state border. The western boundary of Dunklin Co. is the St. Francois River (**Figure 1**).

A prominent ridge within the SLGP is called Crowley's Ridge and the Benton Hills. These elevated land masses consist on Paleozoic rocks, largely Ordovician, and are covered by Tertiary gravels and loess [6]. Crowley's Ridge and the Benton Hills bisect the SLGP, with the land mass between Ozark Escarpment and west of Crowley's Ridge and the Benton Hills called the Advance Lowlands (also called Western Morehouse Lowlands). The Advance Lowlands represent the ancestral channel of the Mississippi River and are generally composed of loamy to silty terraces and back-swamp deposits overlying glacial outwash and valley train. Conversely, the Morehouse Lowlands extend from Crowley's Ridge eastward to the Mississippi River. The Morehouse lowlands consist of terraces of varying textures, back-swamp deposits, and other alluvial environments overlying braided glacial outwash. The modern Mississippi River and its flood plain is the youngest and easternmost feature with meandering channel deposits, natural levees, silty terraces, back-swamp environments, and crevasse splay deposits that characterize the Mississippi River floodplain [7]. Sikeston Ridge and Barnes Ridge (east of Portageville, MO) are low-elevation ridges, composed of coarse-textured materials and both are in the Morehouse Lowlands. Just east of Crowley's Ridge and extending into Dunkin Co. is a terrace system of coarse-texture materials called the Kennett-Malden Prairie. The Charleston Lowland is located primarily in Mississippi Co. and consists of fine to coarse textured materials, composed to recent terrace and back-swamp environments. Between the Benton Hills and the Charleston Lowlands is the Blodgett terrace composed of coarse-textured materials and the Charleston Fan, also composed of coarse-textured materials.

7. Drainage patterns

The study area is bordered on the west by the St. Francois River and on the east by the Mississippi River. Each of these southerly flowing river systems may alternately supply floodwaters or provide surface drainage. A series of dendritic streams and rivers drain the Black River Ozark, the Inner Ozark, and the Outer Ozark Border regions, providing surface waters to the Advance Lowlands and the Morehouse Lowlands. These rivers include: the Black River, White River, Castor River, and the St. Francois River. In addition, small streams provide drainage from the Benton Hills and Crowley's Ridge, providing water to the Advance and Morehouse Lowlands [8].

8. The value of the agricultural productivity

The dominant crops in the study area include: corn (*Zea mays* L.), soybeans (*Glycine max* (L.) Merr), cotton (*Gossypium hirsutum* L.), wheat (*Triticum aestivum* L.), and rice (*Oryza sativa* L. (indica)). Other commonly cultivated crops include: potatoes (*Solanum tuberosum* L.), sweet potatoes (*Ipomoea batatas* (L.) Lam), cowpeas (*Vigna unguiculata* (L.) Walp), winter squash (*Cucurbita* sp.), sorghum (*Sorghum bicolor* L.), watermelons (*Citrullus lanatus* (Thunb) Matsum, and Nakai), peanuts (*Arachis hypogaea* L.), and a variety of vegetable crops. The study area is the most intensively cultivated region in Missouri and having the longest growing season.

The area also has the highest percentage of level and tillable land, of which 60–70% is irrigated with abundant groundwater resources. Animal agriculture is very small, consisting of a few beef cattle and horse operations.

In southeastern Missouri, there are 4133 farms [9]. Cape Girardeau County has more than 1100 farms, thus approximately one-quarter of all farms of the eight-county region are in Cape Girardeau County. In the Mid-South region, Stoddard County has the largest number of farms, many of which are smaller farms on upland hills. The range in farm size varies from small land parcels (less than several hectares) to large farming operations (greater than 5000 hectares) [9].

The study area's population is low, with 223,000 persons. To estimate the values of the agriculture production, the annual crop production by county [9] was multiplied by commodity prices for that time [9]. The annual value of the agriculture production from cropping systems is \$1.27 billion (2016). The five-year (2012–2016) average value of production for the dominant crops include: (i) corn (\$325 million) and (ii) soybeans (\$525 million), cotton (\$200 million), rice (\$150 million), and wheat (\$75 million). For the same five-year period, the mean crop yields are (i) corn (8844 kg/ha), (ii) soybeans (2722 kg/ha), cotton (1177 kg/ha), rice (7706 kg/ha), and wheat (3965 kg/ha).

To estimate the agribusiness sales of production inputs, the product of the county harvested acreages [9] and the University Missouri crop budgets [10] were utilized. The profitability of the agribusiness sector includes: (i) seed sales for corn (\$47.38 million), soybeans (\$77.94 million), wheat (\$7.88 million), cotton (\$29.52 million), and rice (\$5.25 million), (ii) fertilizer sales for corn (\$57.8 million), soybeans (\$51.5 million), wheat (\$14 million), cotton (\$17.6 million), and rice (\$19.8 million), and (iii) herbicide sales for corn (\$14.1 million), soybeans (\$44.3 million), wheat (\$5.6 million), cotton (\$14.5 million), and rice (\$16.1 million).

9. The geological history of the study area

The Mississippi River embayment was initially created by an ancient down warping of the crust, presumably by tectonic forces. Confining our discussion to the Pleistocene-Holocene the ancestral Mississippi River occupied an Advance Lowland course until the late Wisconsin sub-stage [6, 11, 12]. These authors proposed that the diversion of the Mississippi River through the Bell City—Oran Gap, abandoning the Advance Lowlands and entering the Morehouse Lowlands, was initiated approximately 17,000 year BCE (before common era) and was complete by 11,500 year BCE. By 9800–9900 year BCE, the Mississippi River changed from a braided river to meandering river, passing through the Pemiscot Bayou [12]. After the diversion, the advance lowlands continued to receive sediment from the Ozark Plateau, principally from the Little Black River, the Current River, the Spring River, and the White River. Blum et al. [13] proposed that the Bell City—Oran Gap diversion into the Morehouse Lowlands occurred before 60,000 year BCE, thus placing the Bell City—Oran Gap diversion before the Wisconsin glaciation. Royall et al. [12] proposed that the Ohio River produced two braided stream terraces in the Morehouse Lowlands between Crowley's Ridge and Sikeston Ridge.

Blum et al. [13] map Sikeston Ridge as a late Wisconsin valley train having a very thin loess capping of Peoria Loess. Blum et al. [13] further attribute the Blodgett terrace as a braided terrace deposit of the Ohio River, which was entrenched within the Cache River Valley (Illinois). Based on carbon dating, Blum et al. [13] place the Charleston Fan as a Mississippi River feature formed during the creation of Thebes Gap (10,590 year BCE).

Approximately 9000 year BCE, the Mississippi River diverted through Thebes Gap and flowed east of Sikeston Ridge [12], creating the Charleston Alluvial Fan. The study area has been extensively modified by seismic activity, featuring sand blows, sand boils, clastic dikes, liquefaction, changes in stream drainages, and subsidence [14–16]. A prominent trend of earthquake epicenters has been related to deep-seated folds and igneous intrusions [16]. Loess deposition as a capping on soils in the advance lowlands shows both the stage of development and bisect nature of these soils [17].

10. The southeast lowlands groundwater province in Missouri

The Southeast Lowlands Groundwater Province in Missouri (SLGP) spans 10,142 km² and contains 15.2% of the State of Missouri's groundwater, estimated at 287 billion m³. The Cretaceous age McNairy aquifer crops out (at or near the surface) on the flanks of Crowley's Ridge and the Benton Hills [18]. In Stoddard County and Butler County, the McNairy formation primarily underlies alluvial materials, whereas in Dunklin County and Pemiscot County the McNairy formation is reached by wells having a depth of 600 m. In Dunklin County and Pemiscot County where wells are in thick and clean sands, the water yields range from 570 to 2800 L min⁻¹. Overlying the McNairy formation, the Clayton Owl Creek and Porter's Creek clay formations constitute confining layers. Water from the McNairy formation in the northern regions along Crowley's Ridge are classified as iron rich, calcium-magnesium carbonate type waters, whereas waters from the McNairy formation in the southern portion of southeastern Missouri are sodium chloride type waters.

The Wilcox Group is composed largely of Tertiary-age sands, some regions having minor inclusions of lignite and clay. The Wilcox aquifer is commonly separated into the upper and lower Wilcox aquifers because of sand grain size distribution patterns. The Wilcox aquifer overlies the Porter's Creek clay and is largely absent in northern Stoddard County and attains thicknesses greater than 427 m in Pemiscot County and Dunklin County. Water yields from the Wilcox in Stoddard Co. are approximately 2900 L min⁻¹ and in Pemiscot County are approximately 6400 L min⁻¹. The water composition is calcium-magnesium carbonate or calcium carbonate [18]. The Claibourn aquifer lies on the Wilcox aquifer. The Claibourn aquifer is separated in the upper, middle, and lower Claibourn aquifers, with the upper and middle Claibourn aquifers separated by a layer of thin, clayey materials that act as a confining unit (aquitard).

The Mississippi River Valley Aquifer (the Southeast Lowlands Alluvial Aquifer) consists of unconsolidated clay, silt, sand, and gravelly textured alluvium. Groundwater usage of the Mississippi River Valley Aquifer constitutes approximately 92% of the groundwater

withdrawal in southeastern Missouri. These alluvial materials were largely deposited by the ancestral Mississippi and Ohio River systems, coupled some prominent deposits by the Black, St. Francois, and Little River systems. Alluvial thickness is variable, with typical thicknesses west of Crowley's Ridge ranging from 15 to 45 m, whereas the alluvial thicknesses in Mississippi, Pemiscot, and Dunklin Counties average 76 m. These unconfined aquifers are baseflow recharged annually from the Mississippi River, other prominent rivers and land drainage ditches. Water yield ranges from 3800 to 11,360 L min⁻¹; however, although water level fluctuations do occur between wet and dry seasons, no long-term depletions have been observed [18].

11. Observations of water levels in test wells in Southeastern Missouri

The study area is extensively irrigated, with many counties having center pivot, furrow and flood irrigation covering 60–70% of the landscape. Ten wells operated and continuously monitored by the United States Geological Survey (USGS) are located across the survey area [19], which sample groundwater associated in the unconfined surficial (alluvial) aquifers. The depth to the mean water table ranges from 1 to 8 m.

For example, in the community of Delta, Missouri, the USGS water level monitoring well continuously documented well water levels centered around 5–7 m below the land surface (**Figure 2**). During very dry summers, the water levels subsided to approximately 8 m and then the water levels rebounded during the winter/spring season to approximately 4.6 m from the surface. In each year and for each of the test wells, the wetter winter/spring season permitted aquifer recharge because of rainfall infiltration and baseflow.

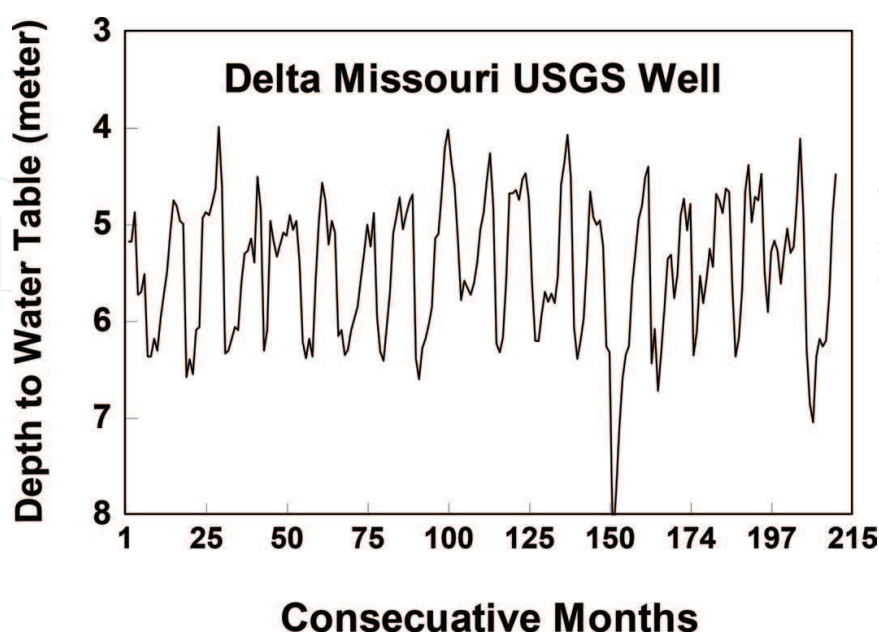


Figure 2. Water depth levels for the Delta Missouri USGS monitoring well from 2000 to 2018 [19].

12. Soils and soilscapes

In the study area, presentative soil orders (US Soil Taxonomy) include: Alfisols, Entisols, Histosols, Inceptisols, Mollisols, and Vertisols. Landforms include: alluvial fans, splays, flood plains and backswamp deposits, ox-bows and meander channels, Holocene and Pleistocene terraces of coarse to fine-silty textures, and modern to old natural levees and constructed levees. A great portion of the landscape has been recently land-graded for furrow and flood irrigation.

For example, the Cooter-Hayti-Portageville Soil Association rests on Holocene sediment having a transitional texture from sandy alluvium to silty-loamy alluvium to clayey alluvium (**Figure 3**). The poorly drained Portageville clay series (Vertic Endoaquolls: Ap/A-Bg-Cg) exhibits soil organic matter accumulation and soil profile depletion of Fe attributed to anaerobic conditions, whereas the Cooter (Fluvaquentic Hapludolls: Ap/A-2C1-2C2) is a bisqual soil (clayey over sandy) featuring few subsurface redoximorphic features because of the quartz parent material. The fine-silty, poorly drained, non-acid Hayti series (Mollic Fluvaquents: Ap-C) developed in recent silty alluvium lacks soil profile development because of the lack of time for soil profile horizonation.

The Memphis-Loring-Calhoun-Foley Association rests in the Advance Lowlands (also called the Western Morehouse Lowlands) with the fine-silty, deep, strongly acid, well-drained

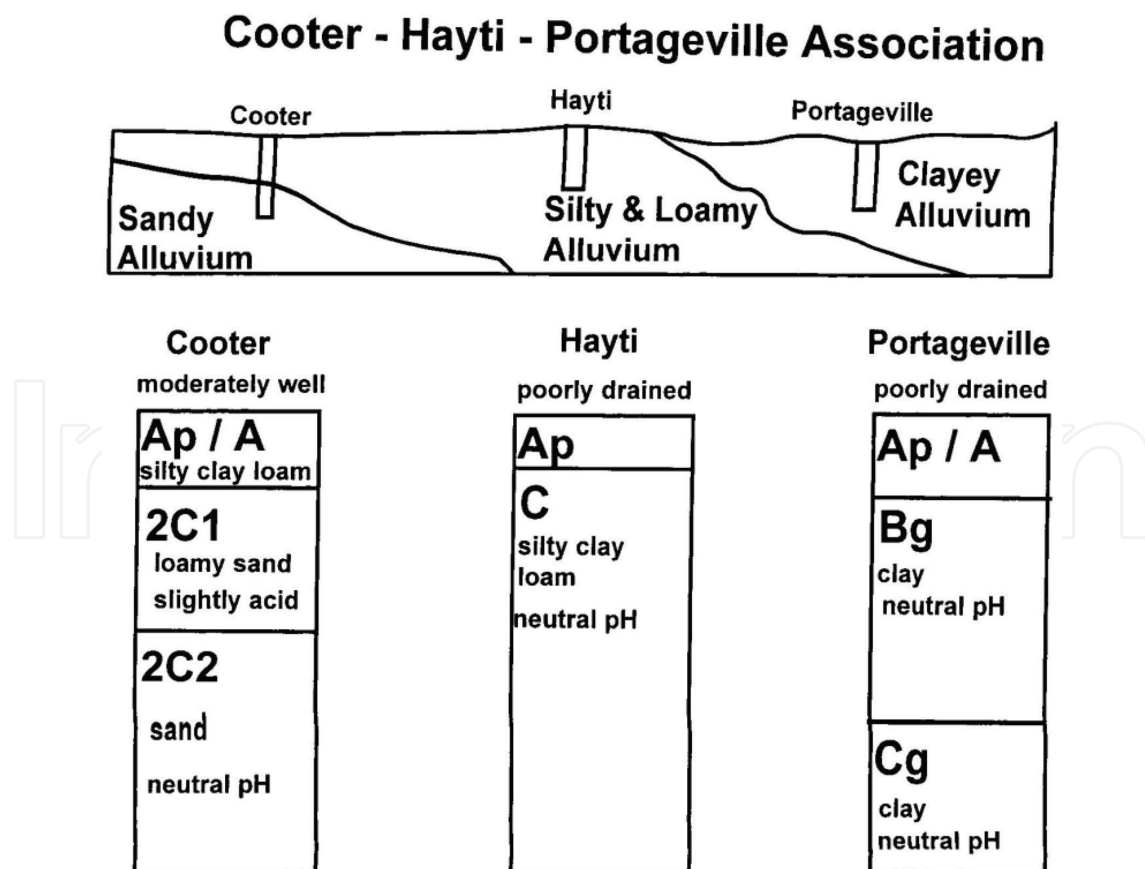


Figure 3. The Cooter-Hayti-Portageville Association.

Memphis (Typic Hapludalfs: A-E-Bt-C) resting in thick loess on Crowley’s Ridge (**Figure 4**). The fine-silty, strongly acid, moderately well-drained Loring series (Oxyaquic Fragiudalfs: A-Bt-Btx-C) possesses a well-developed fragipan whose surface represents a transition from Pleistocene silty alluvium to the overlying loess. The poorly drained, fine-silty Calhoun (Glossaqualfs (Ap-Ed-Btg-BCg) and Foley (Natraqualfs: Ap-Eg-Btng/E-Cg) series rest on Pleistocene terraces and may have thin loess mantles. The presence of argillic horizons in these soils indicate their relative more mature age when compared with the previous Holocene soils.

The Sharkey-Alligator Association is a commonly occurring association in the Morehouse lowlands (**Figure 5**). The soils of the Sharkey series consist of very deep, poorly and very poorly drained, very slowly permeable soils formed on level to nearly level backswamp positions along modern and former channels of the Mississippi River. The Alligator series consists of very deep, poorly drained, very slowly permeable soils formed in clayey alluvium in backswamps and sloughs.

The very-fine textured Sharkey soils (very-fine, smectitic, thermic Chromic Epiaquerts) have an Ap - Bssg - Bssyg - Bssg soil horizon sequence. The soil colors range from dark and very dark grayish brown in the silty clay to clayey Ap soil horizon to dark gray and gray in the clayey cambic horizon. The near surface horizons are slightly acid to neutral and deeper soil

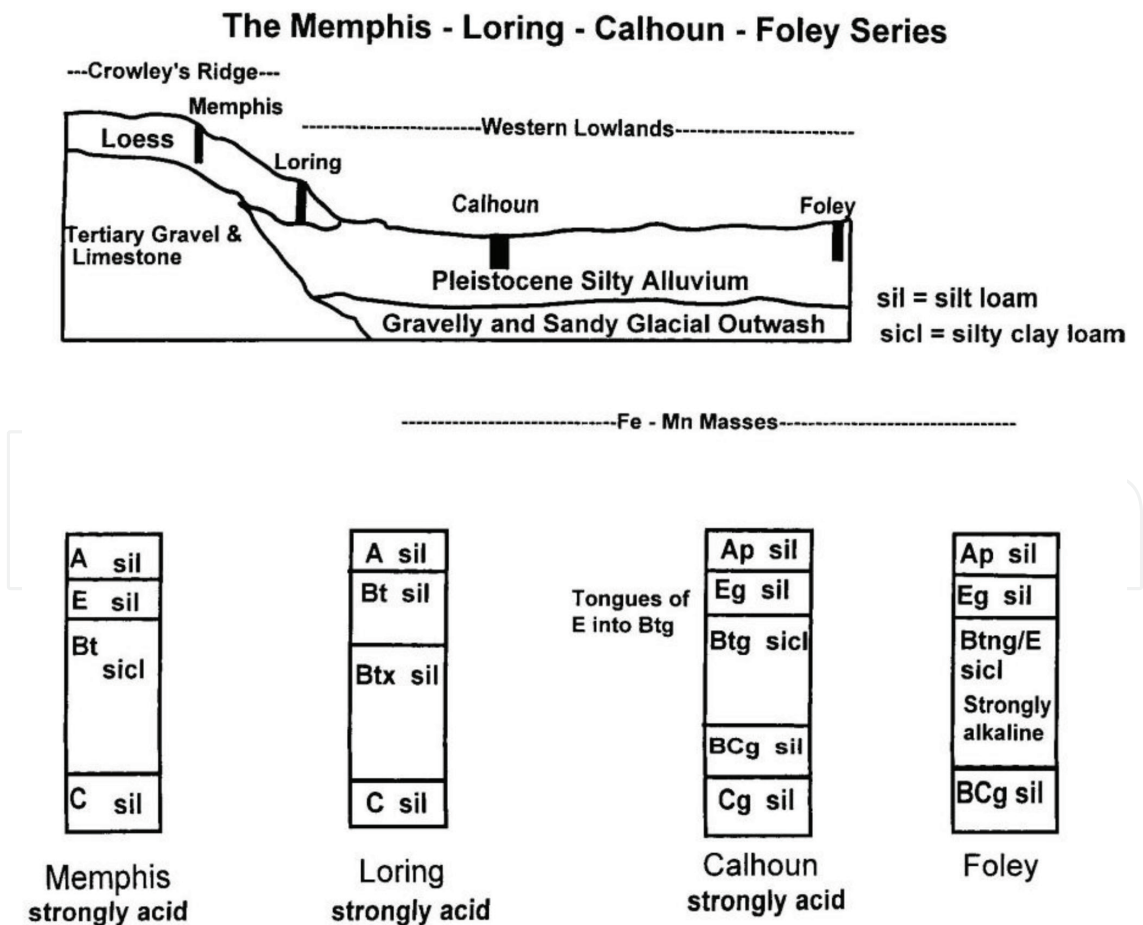


Figure 4. The Memphis-Loring-Calhoun-Foley Association.

Sharkey - Alligator Series on Clayey Alluvium

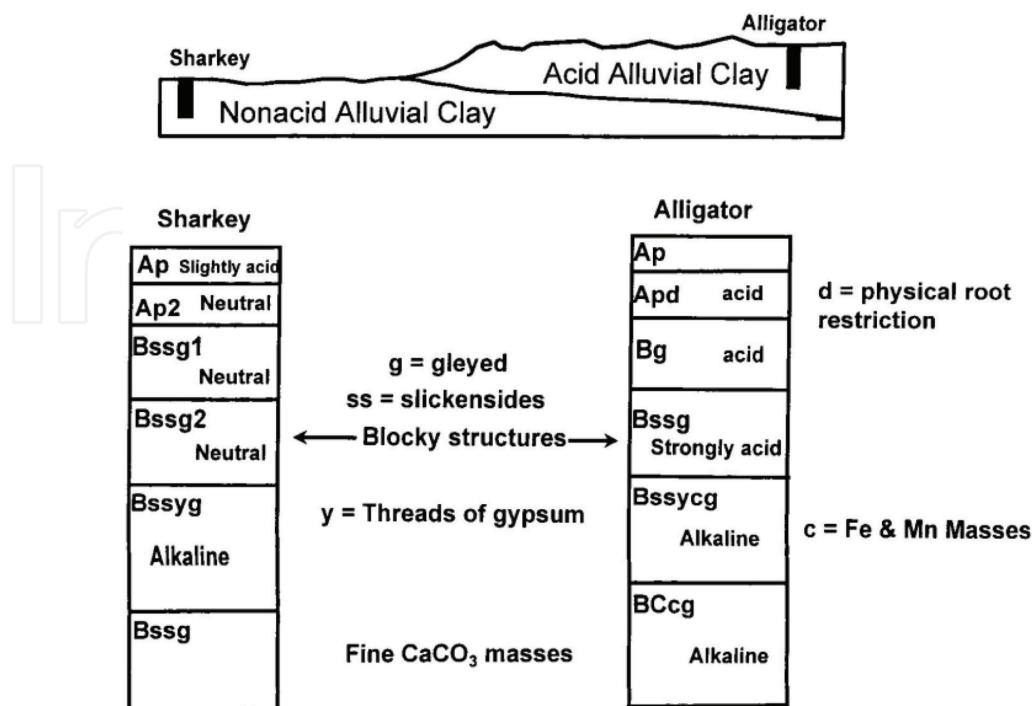


Figure 5. The Sharkey-Alligator Association.

horizons are neutral to moderately alkaline. The cation exchange capacity (CEC) is generally high, attributed to the abundance of smectic clay. The soils of the very-fine Alligator series (very-fine, smectitic, superactive, thermic Chromic Dystraquerts) present an A - Bg - Bssg - Bssycg soil horizon sequence, with all horizons having a clayey texture. These soil horizons are commonly very strongly acid. The grayish brown Bssg and Bssycg horizons have coarse wedge-shaped structures with grooved slickensides on their surfaces. The CEC is generally high, attributed to the abundance of smectite clay.

With the advent and continued maintenance of the Little River Drainage Project the region's hydrologic conditions have been irreversibly altered towards achieving agricultural productivity [20]. Because the Little River Drainage System and its extensions are relatively new and given that soil changes are a function of time and no previous soil baseline data exists prior to land drainage, it is difficult to quantify soil changes because of regional land drainage. Yet soil evolution has been altered and the expected macro-soil changes likely include: (i) loss of accumulated soil organic matter because of oxic soil conditions, (ii) soil acidification coupled with nutrient leaching, (iii) deeper soil water tables resulting in fewer near-surface alternating episodes of soil oxidation-reduction, (iv) loss of soil structure attributed to tillage, land grading, and loss of soil organic matter, (v) changes in the microbial communities, (vi) changes in the invertebrate and vertebrate populations, and (vii) acceleration of mineral weathering intensities, particularly alteration of smectites to kaolinite and apatite dissolution. Because of agriculture, fertilization practices have increased the phosphorus and potassium soil test values.

Horizon	Texture	Color	pH	CEC	SOM	ESP
A	Silt loam	Grayish brown	6.0	14.9	4.3%	<1%
E	Silt loam	Light brownish gray	5.1	12.8	1.9%	<1%
BE	Silty clay loam	Pale brown	5.2	14.5	1.9%	<1%
Btg	Silty clay loam	Light brownish gray	5.4	26.8	1.7%	2.0%
Btgn	Silty clay loam	Grayish brown	7.3	18.0	1.4%	18.0%

CEC is cation exchange capacity (cmol kg⁻¹); SOM is soil organic matter (%).
 Btg – argillic horizon (Bt) that is gleied (g or low chroma colors).
 Btgn – Btg horizon that has natric characteristics (high exchange sodium percentage (ESP)).

Table 1. The essential properties of the Overcup soil series in an old growth natural forest.

All soil evolution is a complex interplay between horizonation (development of diagnostic soil horizons) and haploidization (the phenomena of organisms and vegetation altering the soil profile to reduce the expression of soil horizons). Land drainage should support the intensity of soil processes to create and maintain soil horizons, particularly albic and argillic horizons. Conversely, loss of soil organic matter will alter mollic (high base saturation and high soil organic matter) and umbric (low base saturation and high soil organic matter) epipedons to orchric (low organic matter) epipedons. Wetlands are commonly acknowledged to purify surface waters and facilitate surface water transfer to shallow aquifers. There is growing concern that land drainage and the associated agriculture will promote nutrient migration and support fresh water eutrophication. Installed levees prevent river flooding in selected areas, leading to greater flooding elsewhere on lands not levee protected. Irrigation may lead to aquifer overdraft; however, this issue is not apparent in this study area.

For example, the Overcup soil series from the Advance Lowlands (fine, smectitic, thermic Vertic Albaqualfs) are very deep, poorly drained, very slowly permeable soils that formed in alluvium. Soil analysis by the authors of the Overcup soil series in both long-term deciduous forest settings and modern rice production fields (unpublished) demonstrate that considerable soil organic matter contents are evident in the forest settings (**Table 1**), whereas the production fields have diminished near-surface soil organic matter contents. The Overcup soil series shows considerable gray color patterns because of seasonal or fluctuating soil water tables within the solum. Soil acidification is evident in the upper argillic horizon, a feature attributed to base removal by leaching. The lower argillic horizon shows a neutral to alkaline pH with a considerable exchangeable sodium presence because restricted drainage has not permitted base leaching, especially including exchangeable sodium. Thus, the placement of cover crops in rice production fields should re-establish soil organic matter contents in the near-surface soil horizons.

13. Policies and practices supporting soil and water sustainability

Currently Federal, State, and agricultural producer partnerships are creating policies and farming practices that support ecosystem health and farm profitability [21]. The goal is to support

sustainable and profitable agriculture, while identifying farming practices that are wetland suitable, even when the wetland has been altered by previous land drainage projects. A corollary is attempting to identify wetland benefits and reinstitute practices to return or augment wetland benefits to these altered landscapes while preserving agriculture productivity. One key initiative includes “soil health”. Soil health (soil quality) is defined as the continued capacity of soil to function as a vital living ecosystem that sustains plants, vertebrate and invertebrate animals, microorganisms, and humans [22]. This definition speaks to the importance of managing soils to optimize living organisms that contribute to maintaining soil structure, soil organic matter, and functioning nutrient soil and plant connectivity. Considering soil as a living ecosystem reflects a fundamental thinking shift towards nutrient management for plant growth, supporting the soils ability to absorb and hold rainwater for use during dryer periods, filter and buffer potential pollutants from leaving fields, and provide habitat for soil microbes to flourish and diversify. This website [22] provides an annotated bibliography with citations of current literature on soil health initiatives that support water availability, soil structure improvement, soil organic matter optimization (including promotion of active carbon contents), nutrient availability, and limited nutrient transport of nutrients from farm fields to fresh water resources.

A key land practice associated with soil health is the establishment of cover crops. We define cover crops as grasses and legumes cultivated to provide cropland vegetative cover during the off-season to support soil carbon accumulation, improved soil structure (including reduced soil compaction), improved water availability, and substantial reduction in both water and wind induced soil erosion. Our cover crop programs frequently rely on establishment cereal rye (*Secale cereale* L.), crimson clover (*Trifolium incarnatum* L.), and canola (*Brassica napus* L.); however, many producers and extension services support other plant compositions. In early spring, the cover crops will receive chemical burndown with the new crop established with a no-till grain drill/planter into the existing cover crop residue.

USA has established the Mississippi River Basin Healthy Watersheds initiative across 13 USA states [21] to limit the Mississippi River’s nutrient and sediment loads. The initiative supports direct payments to agriculture producers to establish erosion and nutrient migration mitigation, primarily through the Environmental Quality Incentives Program (EQIP) and the Agriculture Conservation Easement Program (ACEP). Nutrient reduction strategies are tailored to individual states. Wetland restoration is a key and central provision wherein marginal land is returned to a wetland status.

Southeast Missouri State University and the United States Department of Agriculture—Natural Resources Conservation Service have partnered to address nutrient transport from production agriculture. The development of Edge of Field Technologies is gaining producer acceptance and has witnessed the establishment of denitrification bioreactors to intercept tile drainage effluent to render the effluent comparatively free of $\text{NO}_3\text{-N}$. From 2015 to the present, the denitrification bioreactor at the David M. Barton Agriculture Research Center effectively reduced nitrate-N concentrations from between 10 and 100 mg L^{-1} $\text{NO}_3\text{-N}$ to less than 10 mg L^{-1} $\text{NO}_3\text{-N}$ [23]. Currently, Southeast Missouri State University and the United States Department of Agriculture—Agriculture Research Service has been active in pumping nitrate and phosphate bearing tile drainage effluent into off season water retention basins to reapply the water as an irrigated source during the growing season. The goal is to reduce aquifer depletion. This

research is also investigating whether the stored off-season water may be passed through a denitrification bioreactor and then returned to the aquifer, thus limiting aquifer overdraft with high quality water replacement. Rice production is an important crop in the study area. Recently, arsenic uptake has become an issue. Aide et al. [24–26] investigated different irrigation practices and determined that furrow irrigation would provide similar yields, substantial limit transference of arsenic to paddy rice and reduce water application rates and aquifer overdraft.

Observed and perceived carbon-cycle changes attributed to the wetland conversion project to the atmosphere-plant-soil continuum include: (i) wetland forest vegetation replaced by annual monocot and dicot agricultural plantings resulting in reduced carbon sequestration, (ii) carbon loss because of grain harvesting and because of enhanced soil oxidation by the combined effects of land drainage and tillage, and (iii) increased soil temperatures [1]. Current technologies practices recently implemented to favor restoring soil carbon levels include: (i) improved residue management and the conversion to reduced tillage practices, (ii) off-season cover crop establishment, and (iii) restricted (controlled) drainage technologies and winter irrigation to preserve organic soil carbon. Winter irrigation also provides over-wintering nesting sites for migratory water fowl.

14. Conclusion

A large-scale agriculture region in Missouri was converted from its wetland status to cropland in the 1920s. The loss of hardwood forest and associated wildlife habitat was profound. At the time of the wetland conversion, the benefits of wetland ecosystems were both not understood or appreciated. Approximately 100 years later, we realize the need to reinstate agriculture practices that restore soil health and water quality that the wetland ecosystem provided. We are progressing with best management practices that improve soil carbon replacement, soil structure repair, improving microbial diversity, and appropriate nutrient flux. Plant diversity is still impaired, resting with agriculture monocultures. Wildlife restoration is a far-future goal and flood control and restoring the natural river flow are still critical areas for improvement.

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